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Decreasing the Magnitude of Shear Rates in the FlowCyl

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Abstract:

FlowCyl is an experimental setup (similar to the Marsh cone) that quantifies rheological properties of cement pastes via a parameter called flow resistance ratio. In a previous study by the authors, it was found that the high shear rates in the FlowCyl affects the flow resistance ratio to be dominated by the plastic viscosity of the cement paste. In this numerical study, we use a computational fluid dynamics model to analyse how the magnitude of shear rates can be reduced in the FlowCyl by changing its geometry (i.e. the height as well as the thickness of both the cylinder and outlet) in order to make the flow resistance ratio also dependent on the yield stress of the cement paste. The numerical model solves the continuity and momentum conservation equation based on the finite volume method. We simulate a Bingham material with yield stress 4.85 Pa and plastic viscosity of 0.38 Pas. The results illustrate that the magnitude of the shear rates can be substantially reduced by decreasing the height of the FlowCyl, as this reduces the hydrostatic head. Increased outlet opening from 8 to 12 mm increases max shear rates whereas the Marsh Cone has lower max shear rates than the FlowCyl.

Keywords: Cement Paste, FlowCyl, Modelling, Rheology

1. Introduction

Rheological properties of cement pastes may be described by the flow resistance ratio, λ_Q. The flow resistance ratio is representing the difference between the accumulated flow flowing through a narrow opening as a function of time in a test material and in an ideal fluid without internal flow resistance (Mørtsell, Maage & Smeplass 1996). By definition, the ideal fluid has a flow resistance value of 0.0, while a flow resistance value of 1.0 represents an extremely viscous fluid (Mørtsell 1996). To calculate the flow resistance ratio, an apparatus called FlowCyl is used. The FlowCyl test is a modification of the Marsh Cone test, and consists of a vertical cylindrical steel tube with a narrow nozzle at the bottom (Mørtsell, Maage & Smeplass 1996). After closing the outlet nozzle, the tube is filled with cement paste up to the level of 15 mm below the top. The paste flows through the nozzle and is directly weighed in a balance, which is connected to a computer recording the accumulated mass as a function of time. The weight increase is recorded every two seconds with a time interval 15 sec until 35 sec after opening the outlet (Mørtsell 1996). The dimensions of the FlowCyl and the Marsh Cone are illustrated in Fig.1.

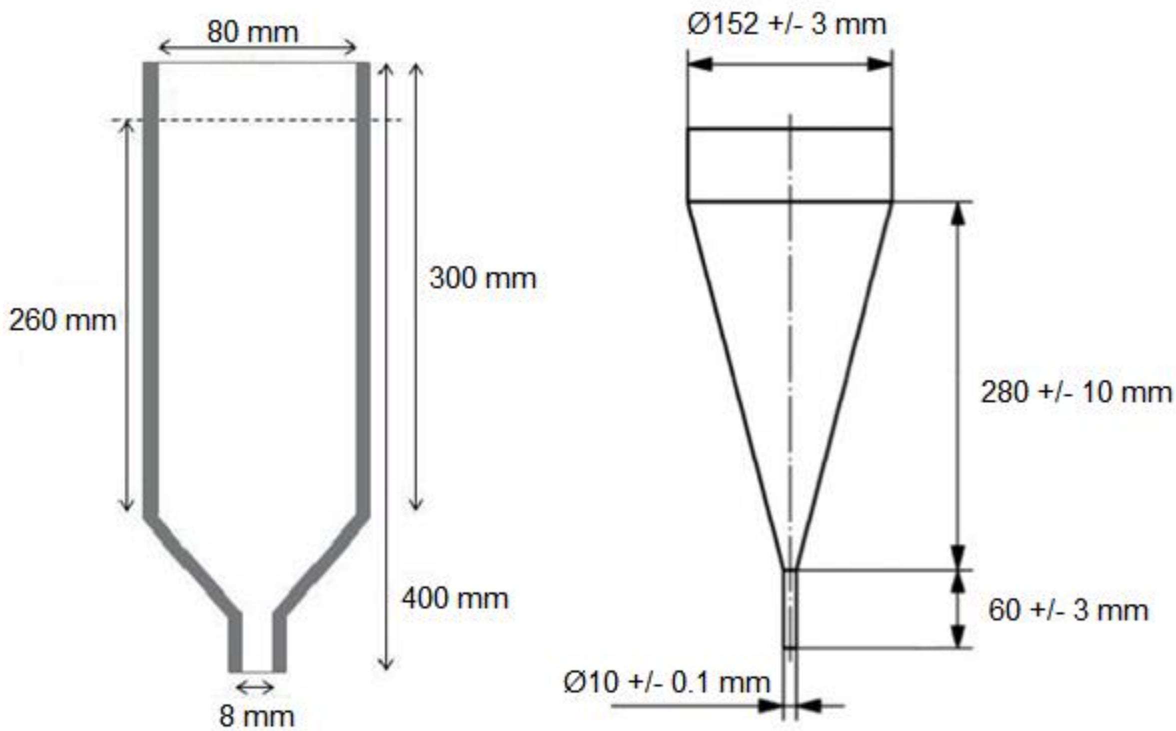

Fig. 1 Dimensions of the FlowCyl (left) and the Marsh Cone (right). (Cepuritis & Smeplass 2016, BFT International).

Several previous studies show that the flow resistance ratio correlates well to the plastic viscosity of the tested material (Cepuritis & al. 2017), and the FlowCyl method has been successfully used to predict the workability of both conventional concrete and lightweight aggregate concrete mixes (Mørtsell 1996, Smeplass 2000). However, when applying to self-compacting concrete mixes, and mixes with high amounts of crushed sand, the FlowCyl has shown to have some limitations (Cepuritis, Jacobsen & Spangenberg 2017, Smeplass & Mørtsell 2001, Hammer & Wallevik 2005, Cepuritis & al. 2017). We think that its ability to measure effects of yield stress may be an important limiting factor. It has been shown (Cepuritis & al. 2017) that some of the limitations for the applicability of the FlowCyl could arise from the fact that the resulting parameter (flow resistance ratio) is mainly only dependant on the viscosity of the tested cementitious matrices, while these materials are known to be two parameter fluids (i.e. yield stress and viscosity).

This paper presents results from a computational fluid dynamics model, which analyses how different geometries of the FlowCyl affect the flow of the cement paste during the experiment. The objective is to investigate how the magnitude of shear rates in the FlowCyl can be reduced, in order to make the flow resistance ratio more dependent of the yield stress of the cement paste.

2. Numerical model

The CFD model that simulates the flow of the cement paste in the FlowCyl was developed in the commercial software, Flow3D, which previously has been used to simulate flow of cementitious materials (Roussel & al 2016). The software finds the primary unknowns (i.e. pressure and velocity fields) by solving the mass- and momentum conservation equations with the generalized minimal residual method. The free surface of the cement paste is computed by a precise interface tracking method called the volume-of-fluid method (Hirt & Nichols 1981, Comminal, Spangenberg & Hattel 2015), and the walls of the FlowCyl are modelled with a no-slip boundary. The cement paste is modelled by a Bingham material model with a yield stress of 4.85 Pa and a plastic viscosity of 0.38 Pas, which corresponds to one of the cement pastes that was analysed in (Cepuritis & al. 2017). Additional information on the CFD model and its validation is presented in (Cepuritis & al. 2018, Cepuritis & al. 2017). Fig. 2 shows the model.

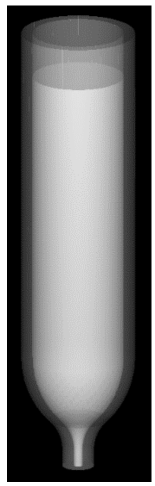

Fig. 2 Initial condition for FlowCyl model (Cepuritis & al. 2017).

3. Results and discussion

Fig. 3 illustrates how the shear rates in the FlowCyl are affected by the height of the cement paste inside the FlowCyl, i.e. the effect of the change in hydrostatic head. The shear rates are investigated 2 sec, 15 sec, 25 sec and 35 sec after the cement paste starts flowing through the nozzle. The lowest height is resulting in a reduction of the maximum shear rate by approximately 60 % from the original geometry. The maximum shear rates are of course always observed at the wall.

The diameter of the FlowCyl is also found to affect the magnitude of the shear rates. Fig. 4 illustrates how an increase in the diameter from 80 mm (standard) to 160 mm, results in an increase in maximum shear rate by approximately 60 %. Hence the flow conditions are clearly not a simple function of the hydrostatic head since there is such a big influence of the diameter of the FlowCyl and hence of the volume of paste.

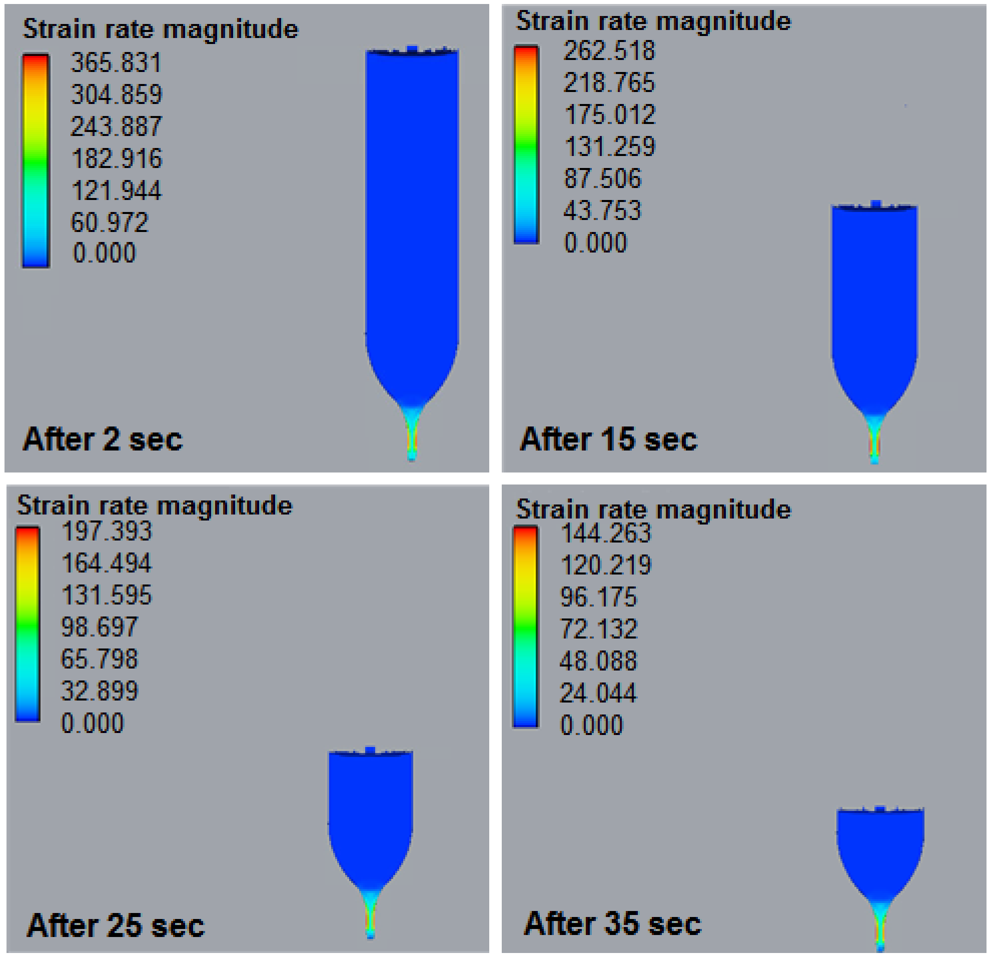

Fig. 3 Effect of hydrostatic head on the shear rates in the FlowCyl.

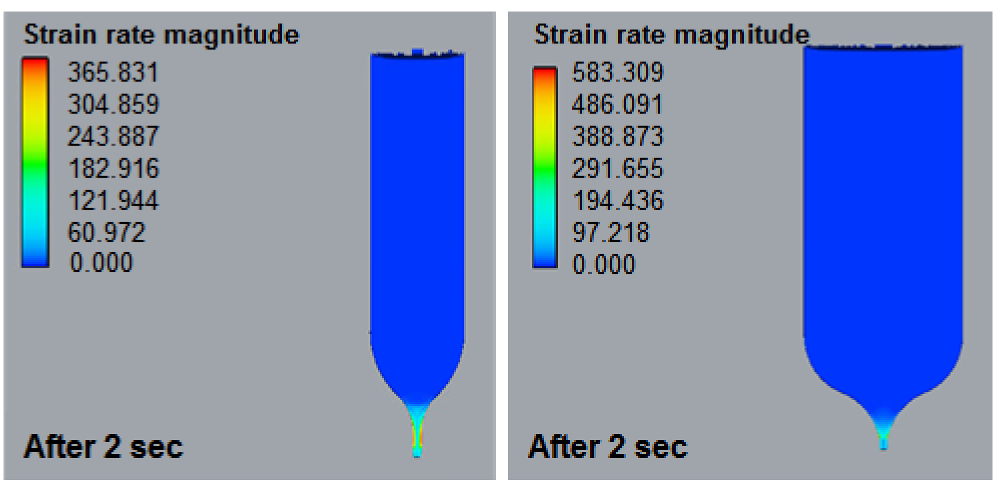

Fig. 4 The effect of increased FlowCyl diameter on the shear rates.

The effect of the outlet diameter on shear rates in the FlowCyl was also investigated. Two cases are simulated, with outlet diameters of 8 mm (standard) and 12 mm, shown in Fig. 5. The increase in outlet diameter leads to an increase in maximum shear rates by almost 30 %.

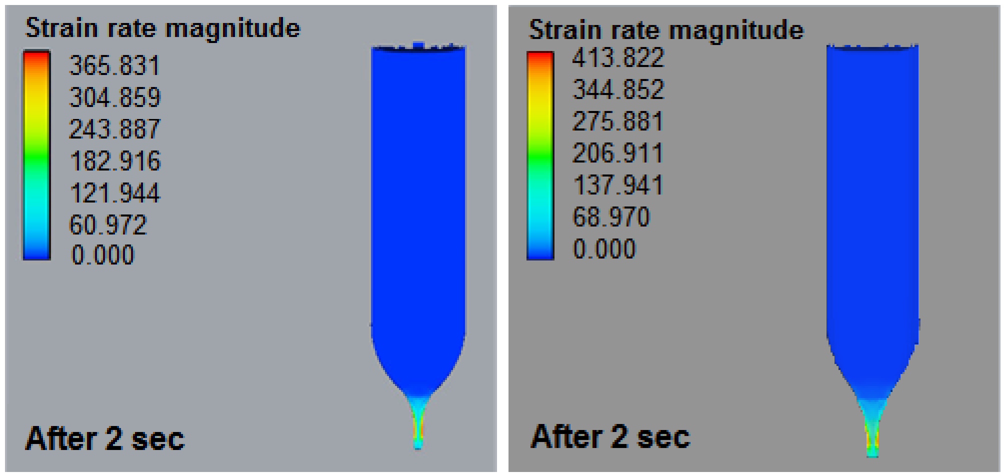

Fig. 5 Resulting shear rates for two different outlet diameters.

The difference in the occurring shear rates in the FlowCyl and in the Marsh Cone was also simulated, and the resulting shear rates after 2 sec are shown in Fig. 6. The lower shear rates in the Marsh Cone is assigned to a lower hydrostatic head, as seen in Fig. 1.

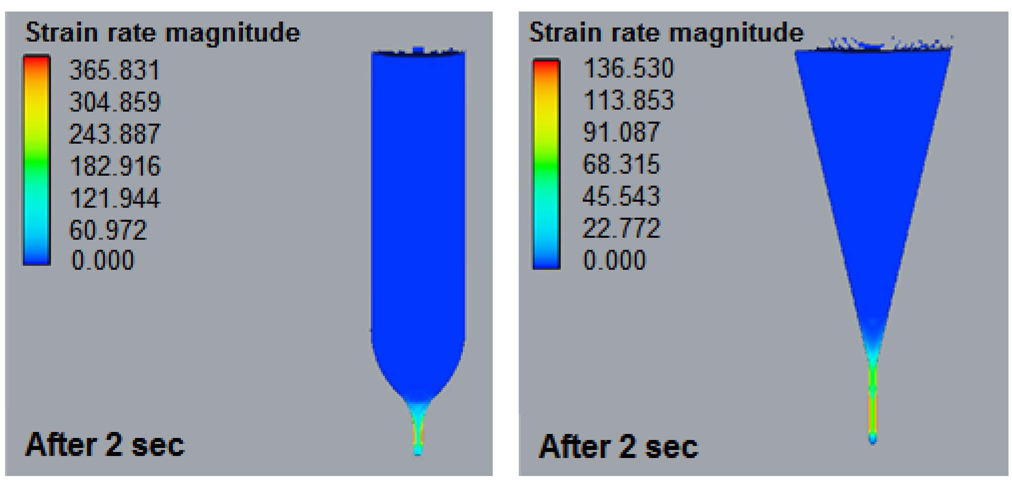

Fig. 6 Difference between the FlowCyl and the Marsh Cone.

The results are encouraging for the development of a simple one-point test based on FlowCyl that is more sensitive to both Bingham parameters. As a first experimental verification towards this goal FlowCyl experiments with materials with different combinations of Bingham parameters yield stress/plastic viscosity (low/low, low/high, high/low and high/high) should be conducted with low and high filling heights.

3. Conclusions

In this paper, the magnitude of shear rates for different modified geometries of the FlowCyl has been investigated with a computational fluid dynamics model. The research has aimed for a reduction of the shear rates at the outlet of the FlowCyl, in order to make the flow resistance ratio also dependent of the yield stress of the cement paste. The simulations found that the magnitude of shear rates decreases with decreasing hydrostatic head. In addition, the maximum shear rates was found to decrease both with decreasing FlowCyl diameter and outlet diameter. When comparing the FlowCyl and the Marsh Cone, the occurring shear rates are lowest for the Marsh Cone. This result is also assigned to the lower hydrostatic head seen in the Marsh Cone. In the future, laboratory experiments will be carried out in order to measure the flow resistance ratio for the same matrix with different filling heights of the FlowCyl.

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